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Method of stabilizing pulsating gas flows in the intake system of a piston engine with turbocharging

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Method of stabilizing pulsating gas flows in the intake system of a piston engine with turbocharging

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Abstract. Piston internal combustion engines (ICE) are the most common sources of energy among heat engines. Currently, most ICEs are equipped with a turbocharging system. Thermomechanical perfection of processes in the intake system largely determines the efficiency of engines. This article proposes a method of stabilizing the pulsating flows in the intake system by installing the leveling grid in the output channel of the turbocharger (TC) compressor. Studies were conducted on an experimental setup, which consisted of a single-cylinder engine and turbocharging system. A constant-temperature thermo-anemometer was used to determine the instantaneous values of the air flow rate and the local heat transfer coefficient. It has been established that the presence of a leveling grid in the intake system leads to a decrease in the turbulence number by up to 25% compared with the basic intake system (while maintaining the flow characteristics). It is shown that the installation of a leveling grid in the intake system of the ICE with TC also leads to a decrease in the heat transfer intensity by up to 15 % compared to the base system. The obtained data expands the knowledge base on the thermomechanics of pulsating flows in hydraulic systems of complex configuration.

1. Introduction

It is known that the efficiency and reliability of an internal combustion piston engine (ICE) with a turbocharger (TC) depends on the perfection of the thermal and mechanical processes in the intake system [1-3]. The gas-dynamic perfection of the design of the intake system of the ICE with TC determines the quality of filling the cylinder with the working fluid and the features of the processes of mixing and combustion. Thermal and mechanical perfection of the intake system affects the intensity of cooling of the working fluid during the intake process and the temperature stresses in the parts and assemblies of the system under consideration.

However, it is obvious that the installation of a turbocharger leads to a significant change in the thermal and mechanical characteristics of the gas flow in the intake system of a piston engine [3-6]. This is due to the fact that the blade mechanism of the turbocharger is a source of external turbulence for the main pressure flow in the intake system of the ICE with turbocharging. External turbulence can significantly influence the character of development and the structure of the boundary layer with values of the turbulence number Tu greater than 0.1 [4, 5]. In turn, this will affect the heat transfer intensity.

A large number of scientists and engineers investigate the influence of various boost systems on the efficiency of piston engines [7-10]. In these works, it has been shown that the supercharging systems based on the turbocharger have not yet exhausted their potential and, accordingly, they are able to improve the performance of power machines based with piston ICE. It should be noted that there is complex work on the improvement of processes in the intake and exhaust systems, input and output channels of the turbocharger, operating modes of the ICE and the TC. In particular, the improvement of the designs of intake and exhaust systems in order to increase the efficiency of the turbocharger and the engine was carried out in studies [11, 12]. Takizawa et al. [13] presented an original method for modeling processes in the TK turbine, which takes into account the specific features of the operation of the blade apparatus and the geometry of the channels. Tang et al. [14] developed a control system for a TK turbine with variable geometry in order to improve the injectivity, environmental friendliness and engine efficiency. Khairuddin et al. [15] experimentally performed gas-dynamic improvement of the intake system in order to increase the efficiency of the turbine and the engine. It should be noted that a small number of studies are carried out by experimental methods, taking into account the gas-dynamic unsteadiness characteristic of piston engines with TC.

Thus, the purpose of this study was to develop a method for the thermal and mechanical improvement of processes in the intake system of a piston engine with a turbocharger by stabilizing the pulsating gas flows.

2. Experimental base and description of the research task

The studies were carried out on an experimental stand (Fig. 1, a), which consisted of a single-cylinder model of a piston engine and a turbocharger with an independent drive system. The cylinder diameter was 82 mm, the piston stroke was 71 mm. The turbocharger of the model TKR6 was used in this study.

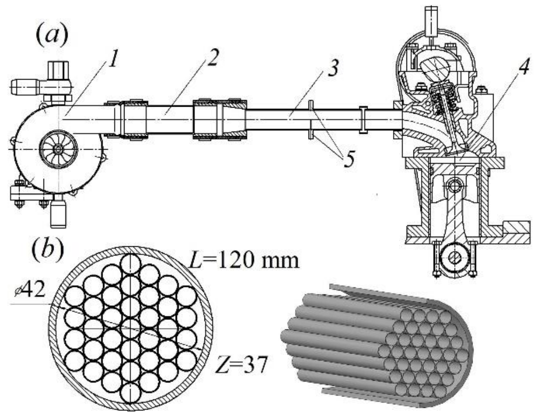

Figure 1. General view of the experimental setup (*a*) and configuration of the leveling grid (*b*): *1* – turbocharger; *2* – compressor output channel; *3* – intake pipe; *4* – piston engine; *5* – thermo-anemometer sensors.

The piston engine was driven by an electric motor. The crankshaft rotational speed varied in the range from 600 to 3000 rpm. The turbocharger rotor was rotated by supplying compressed air to turbine blades from an external source. The rotational speed of the TC rotor was changed in the range from 30000 rpm to 50000 rpm. Air with a temperature of 30-45 °C (depending on the operating mode of the turbocharger) was used as the working fluid. The pressure in the intake system ranged from 0.111 MPa to 0.146 MPa.

The instantaneous values of the air flow velocity w_x and the local heat transfer coefficient α_x in the intake pipeline were determined during the experiments (Fig. 1, a). A constant-temperature hot-wire anemometer (thermo-anemometer) was used to determine the w_x и α_x. Two different types of sensors were used. To determine the velocity w_x, a sensor with a free filament was used, which was located perpendicular to the channel axis. To determine the local heat transfer coefficient α_x, a sensor with a filament located on the surface of the fluoroplastic substrate was used. It was installed flush in the intake pipeline. Systematic error of air flow rate measurement was 5.5 %, local heat transfer coefficient was 10.0 %. The method of determining the w_x and α_x is described in detail in article [16]. The engine's crankshaft rotation frequency n was determined by a tachometer (inductive sensor and a disc with tags). The TC rotor rotation frequency n_{Tc} was determined by a non-contact digital tachometer (laser and reflective label). The data from the sensors entered the analog-to-digital converter and then to the computer for further processing.

The leveling grid based on the honeycomb principle was used to stabilize the gas flow. The geometric dimensions of the leveling grid under consideration are shown in Fig. 1, b. It consisted of 37 honeycombs with a diameter of 5.5 mm each, a length of 120 mm. The leveling grid was installed in the compressor output channel in front of the intake pipeline of the engine (Fig. 1, a).

3. Research results and discussion

Data on the air flow velocity w_x and the local heat transfer coefficient α_x for the engine's working cycle for the base intake system and intake system with leveling grid for one mode of operation of the ICE and TC are presented in fig. 2.

From fig. 2 it can be seen that the installation of a leveling grid in the output channel of the compressor leads to a noticeable smoothing of the amplitudes of the pulsations of the air flow velocity in the intake system of a piston ICE during the entire working cycle. It should be noted that the maximum velocities remain almost the same for both intake systems under study (the difference does not exceed 5%, which is within the experimental error limits).

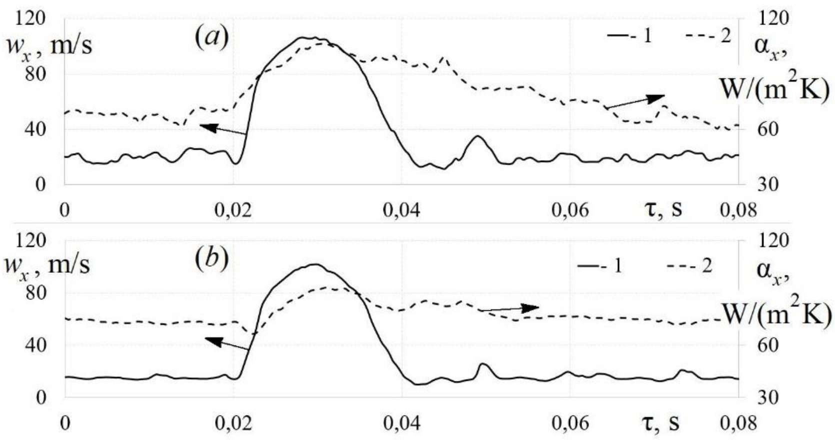

Figure 2. Dependencies of speed w_x (1) and local heat transfer coefficient α_x (2) over time for the basic intake system (*a*) and the intake system with leveling grid (*b*) for n = 1500 rpm and n_{Tc} = 42000 rpm.

The installation of the leveling grid in the output channel of the compressor also leads to a significant smoothing of the dependence $\alpha_x = f(\tau)$ in the intake system of the piston engine with a turbocharger (Fig. 2). At the same time, the presence of the leveling grid leads to a decrease in the maximum values of the local heat transfer coefficient by 14 % compared to the base intake system.

To quantify the stabilization degree of the pulsating air flow in the intake system of a piston engine, the turbulence number Tu over the working cycle was calculated for both configurations under study at different modes of operation of the ICE and the TC (Fig. 3, a and Fig. 4, a). Also, the average values of the local heat transfer coefficient $\overline{\alpha_x}$ for the period of the intake process (heat transfer intensity) for the basic intake system and the intake system with a leveling grid were determined (Fig. 3, b and Fig. 4, b).

A comparative analysis of the degree of turbulence in the intake systems of different configurations shows that the installation of a leveling grid in the compressor output channel leads to a decrease in Tu by up to 25% compared with the basic intake system. This indicates the high efficiency of this method for stabilizing the pulsating flows in the intake system of a piston ICE with TC. Stabilization of the pulsating flow in the intake system can have a positive effect on the efficiency of the TC compressor.

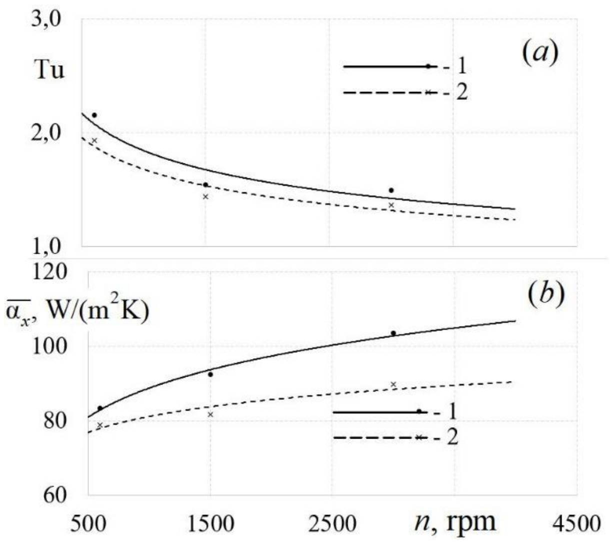

Figure 3. Dependences of the turbulence number Tu (*a*) and the local heat transfer coefficient α_x (*b*) on the engine crankshaft speed *n* for the basic intake system (1) and the intake system with the leveling grid (2) at n_{Tc} = 42000 rpm.

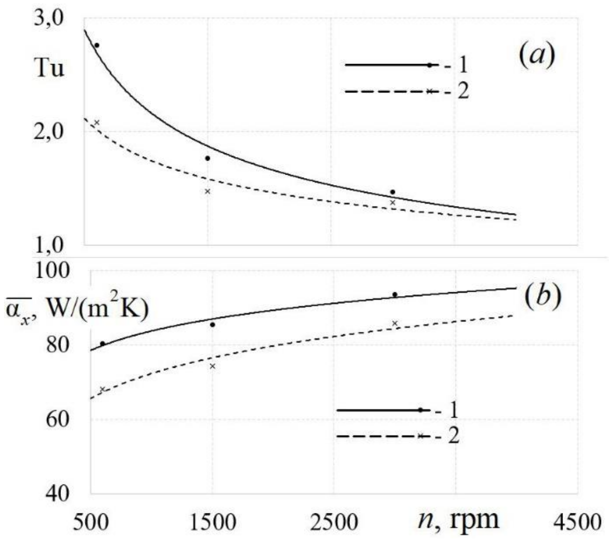

Figure 4. Dependences of the turbulence number Tu (*a*) and the local heat transfer coefficient α_x (*b*) on the engine crankshaft speed *n* for the basic intake system (1) and the intake system with the leveling grid (2) at n_{Tc} = 50000 rpm.

At the same time, the differences in the Tu values are reduced and do not exceed 5 % with an increase in the engine crankshaft speed. It can also be noted that the differences in Tu values increase with an increase in the turbocharger rotor speed. Thus, the maximum differences in the turbulence number are 10.3 % at n_{Tc} = 42000 rpm, and the differences reach already 24.6 % at n_{Tc} = 50000 rpm. According to the authors, this is due to the excessive performance of the turbocharger in these operating modes, i.e. the air consumption of the turbocharger (at n_{Tc} = 50000 rpm) significantly exceeds the air consumption of the piston engine at *n* = 600-1500 rpm. As a result, reverse waves occur in the intake system, which are the source of gas-dynamic flow oscillations. In turn, the installation of a leveling grid leads to the smoothing of these oscillatory phenomena in a pulsating flow in the intake system of a piston ICE with a TC.

It should be noted that the presence of a leveling grid in the intake system of a piston engine with a turbocharger does not reduce the air flow through the engine cylinders. Differences in consumption characteristics are 4-6 %. This is typical for all investigated modes of operation of the ICE and TC.

Installation of the leveling grad in the output channel of the compressor leads to a decrease in the heat transfer intensity in the range from 5 to 15 % depending on n and n_{Tc}. It should be noted that the decrease in the heat transfer intensity occurs in the intake system with a leveling grid in comparison with the base system with increasing turbocharger rotor speed. Thus, the average value of the heat transfer coefficient decreases by about 10 % at n_{Tc} = 42000 rpm, whereas the decrease is already 12.5 % at n_{Tc} = 50000 rpm. According to the authors, the decrease in the heat transfer intensity in the intake system with the leveling grid is associated with the stabilization of the pulsating flow (decrease in the turbulence number), alignment of the flow core and smoothing of the boundary layer on the pipeline surface.

4. Conclusions

The following main conclusions can be drawn from the research.

1. An experimental setup and an automated data acquisition system were developed to study the thermal and mechanical characteristics of pulsating flows in the intake system of a piston engine with a turbocharger.

2. It has been established that the presence of a leveling grid in the compressor output channel leads to stabilization of the flow in the intake system of a piston ICE:

- the curve $w_x = f(\tau)$ is smoothed;
- a decrease in the turbulence number Tu up to 25% compared with the basic intake system is observed;
- the flow characteristics of the working fluid through the engine cylinders are preserved.

3. It is shown that the installation of a leveling grid in the compressor output channel leads to a decrease in the heat transfer intensity in the intake system of a piston ICE with a TC up to 15% compared to the base system. This should lead to a decrease in thermal stresses in the intake system parts and, accordingly, improve the reliability of the engine as a whole [17].

4. The data obtained extend the theoretical knowledge base on the thermomechanics of pulsating flows in hydraulic systems of complex configuration. And they can be used to design intake systems for piston engines with promising technical and economic indicators.

Acknowledgments
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